DOCUMENT RESUME

ED 307 123 SE 050 576

AUTHOR Dumas-Carre, Andree; Caillot, Michel
TITLE Cognitive Aids for Solving Physics Problems.
PUB DATE 89
NOTE 28p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Francisco, CA, March 27-31, 1989). Drawings and tables may not reproduce well.
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Cognitive Processes; Foreign Countries; *Mechanics (Physics); Physics; *Problem Solving; *Science Instruction; *Scientific Concepts; Scientific Principles; Secondary Education; *Secondary School Science
IDENTIFIERS France; *Mental Models

ABSTRACT

Most physics problem-solving studies provide data that indicate problem representation is different between experts and novices. This paper presents "cognitive aids" guiding the process of elaboration of a problem representation through intermediate representations. Intermediate means that the representation is situated somewhere between the verbal description of the problem statement and the final representation. Four cognitive aids are described including goal analysis, motion analysis, event strip, and body-interaction diagram. Two ways for teaching the cognitive aids (specific training session and integrated teaching), their respective assessment, and an interpretation of the results are presented. This paper concludes that student performance for solving mechanics problems can be improved if any teaching aims at helping students to build a useful problem representation, and learning is better if the teaching aid is not separated from the teaching of physics concepts, principles, and laws. (YP)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

Paper presented at the annual meeting of the
American Educational Research Association, San Francisco, March1989.

ED307123

COGNITIVE AIDS FOR SOLVING PHYSICS PROBLEMS

Andrée DUMAS-CARRE & Michel CAILLOT

University of Paris and CNRS

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☒ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

Michel Caillot

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

LIRESPT*

Université PARIS 7

2 Place JUSSIEU

75251 - PARIS CEDEX 05

SE050 576

* Laboratoire Interuniversitaire de Recherche sur l'Enseignement des Sciences Physiques et de la Technologie

BEST COPY AVAILABLE

COGNITIVE AIDS

FOR SOLVING PHYSICS PROBLEMS

The project here presented belongs to the trend of innovative teaching. It is focused on a teaching which aims at improving the students'abilities to solve textbook problems. The domain content on which the project is based is mechanics such as it is taught in physics classes in french high schools.

In this paper we will present what we call "cognitive aids". These cognitive aids are intended to guide the process of elaboration of a problem representation through "intermediate" representations. Each successive representation enriches the student's knowledge about the situation described in the problem statement. Each one is in terms of qualitative concepts. So, the cognitive aids help students to build a qualitative problem representation in such a way that they are prepared to make a plan of solution and to take decisions about which principle or law should be chosen and about which system should be taken into consideration.

We will also present two ways for teaching these cognitive aids, their respective assessment and an interpretation of the results. Then we will conclude about the educational perspectives opened by this project.

1 - THE CENTRAL ROLE OF A PROBLEM REPRESENTATION

A lot of research has been done in the field of solving textbook problems. Several studies are prescriptive and propose a new way of

teaching (REIF,1983; LARKIN et al.,1980; LARKIN,1981; METTES et al.1980, METTES et al,1981). All these projects agree on the fact that the main difference between experts and novices is about the problem representation. Experts elaborate very rich representations all based on physics principles. Novices do not do so. Their representations are often built on surface features (CHI et al.,1981). Almost all the prescriptive methodologies are intended to help students to build a problem representation like the experts' one.

If we agree with the idea that any teaching of a problem solving methodology aims at engaging students in a representation elaboration process, we are not in full agreement with the second idea, that is to be effective the student's problem representation has to be like the expert's one. The expert's representation is generally at a high level of conceptualization, a great part of knowledge remains implicit. The kind of knowledge used in expertise is compiled knowledge. The relations between the different kinds of physics descriptor is not made explicit because they are a part of the implicit knowledge of experts.

Students are not able to build such a representation. As they are beginners in physics, they know only pieces of physics. Their knowledge is less integrated and is not yet compiled. So they need to elaborate "intermediate" representations. Intermediate means that the so-called representation is situated somewhere between the verbal description of the statement and the final representation which is all at once formalized, symbolic, conceptualized and quantitative. The intermediate representations have to be built, when possible, on "intermediate" concepts. An intermediate concept is often a qualitative and not yet formalized concept : it is a basis on which the formalized concept can be

defined. So in mechanics, the concept of interaction is a precursor to the concept of force. Each intermediate representation is limited and partial, and so represents only a part of the knowledge to be developed by the student. It takes into account only one aspect of the situation, it deals with a single kind of descriptor. However a set of intermediate representations with no links between them is not enough to be efficient. It is necessary to connect and to articulate together each partial view in order to get a complete problem representation. Thus a guidance dealing only with the elaboration of intermediate representations is not sufficient. A guidance about the way to relate, to articulate together each limited view is also necessary.

2 - COGNITIVE AIDS AND SOLVING PROCESSES

In order to respond to the double and somehow conflicting requirement of focusing upon a single descriptor and articulating the successive and partial representations, we propose students two complementary processes :

- a process of analysis which pieces down the difficulty through three "intermediate representations" each one dealing with a single kind of concept or physics descriptor;

- a process of synthesis which connects these intermediate representations in order to make clear what is going on qualitatively.

The outcome of this double process is a global and qualitative problem representation which organizes and summarizes information available in the problem statement. When this global and qualitative representation is elaborated, it has become an objective basis on which

the principle to be applied and the mechanical system to be studied can be chosen. A planning of the solution is then possible.

So, in order to guide the student in his/her process of representation building, we provide him/her what we have called "cognitive aids". Why cognitive ? Because they engage the student in a guided thinking process about the physical situation described in the problem statement. But this internal process of guiding thinking should not remain inside the student's mind. It must be conveyed into an external and written product which explicits the mental process. So it can be communicated and then controlled by the teacher. In fact, the internal thinking process is, at the same time, building of a mental representation and elaborating its external expression. The student is requested to produce either written texts or diagrams which, once produced, are the external communication of his/her mental and intermediate problem representation.

Insert around here Fig. 1

The different cognitive aids enable the student to envision the situation through different qualitative concepts. The analysis is performed through the relevant concepts (i.e. position, time and interaction) which lead to the most useful problem representation in mechanics. Each aid enriches the mental representation which has already been built. So gradually the student is led to a full, rich and qualitative envisioning of what is going on in the situation described by the problem statement.

We define four such cognitive aids :

- one deals with an analysis of the problem goal,

- another leads to a kinetic representation,

- the third deals with a space and time representation and the production associated with it is what we have called an "Event Srip",

- the last is in term of mechanical interactions and is named a "Body - Interaction Diagram". This diagram is the expression of a mental representation in terms of bodies and interactions between them.

With these "cognitive aids", instructions are included enabling the student to relate the three intermediate representations (i.e. synthesis process) so that he/she gets a complete and qualitative problem representation.

3 - DESCRIPTION OF THE COGNITIVE AIDS

Among these four cognitive aids, two are very new objects of teaching whereas the two others are a more formalized and organized version of actions usually recommended by the teachers in problem solving processes (but not followed by the students).

3 - 1 - Goal analysis

The goal analysis belongs to the second category. A given situation can be modeled in different ways and thus lead to different problem representations. For example, a car may be modeled either as a single point where the total mass is located, or as a rigid block whith four rotating wheels. The main cue guiding the choice of a model are generally the statement and the question. If the model is not obvious, the type of physics descriptor with which the question deals is a good cue for

choosing a model. Sometimes the student has to translate the question in terms of a physics entity. For all these reasons, the goal analysis is the starting point of the building a problem representation.

Thus the students are asked to transform the problem question, whatever its content, into a question about a physics descriptor and then to link this descriptor to a relevant body at a relevant time. However in many textbook problems, often the question asks clearly for a value of a physics quantity. In this case the elaboration is restricted to the identification of a body and a time.

3 - 2 - Motion Analysis

It also belongs to the second category of teaching object. The students are asked to study the motion of every body present in the situation. They have to class the bodies according to the ones at rest and the others in motion. For the moving objects, they have to see if motion is at constant velocity or at changing velocity, last they have to notice the bodies linked in such a way that they move 'together". This analysis leads to a kinetic representation, first element of the whole representation.

3 - 3 - Event Strip

The Event Strip is a completely genuine object in the present french teaching. It is inspired from Reif's "basic description" (REIF, 1983). Its elaboration starts by a temporal analysis. The students are asked to identify "characteristic" times and "periods" represented by "current"

times. A characteristic time is a time for which "something"(*) changes in the situation. A period is the time elapsed between two successive characteristic times and a "current" time is any time of a period. Once this time identification has been completed the Event Strip elaboration continues by a drawing of the spatial configuration of the bodies (their location, their contacts) for each time. So the Event Strip appears as a succession of snapshots like in a comics strip. In addition, on each drawing are reported and summarized the previous motion analysis and data given in the statement.

Insert around here Fig. 2

3 - 4 - Body-Interaction Diagram

This diagram is also a new object in the physics curriculum. It is a representation in terms of interactions. Usually the concept of interaction is not used in problem solving processes because the students translate directly mechanics problems in terms of forces (and torques) or energy. However interaction is a very powerfull mean of analysis. A physics situation can be described in terms of interaction without having to choose a particular system since an interaction is symmetrical between any pair of bodies. On the other hand, force is disymmetrical because the external environment acts on a particular system. So to speak in terms of force, it is necessary to isolate a system from the rest of universe. In a usual solving process the choice of a system as a first requirement

(*) This term is intentionally vague.

appears to be a non sense since that would mean that the analysis of forces would have been already made ! Another reason to start with interactions rather than forces is that the choice of a particular system is performed at the end of the stage of representation building.

A Body-Interaction Diagram is a drawing where each body is represented by a label and the interactions by double arrows pointing the two labels of bodies under consideration. Its design is very qualitative and based on common sense. For instance, at each contact between two bodies a short range interaction exists. On the other hand, any body having a mass is in interaction with the Earth through a long range interaction (i.e. gravity). Each kind of interaction is represented by specific codes, as shown on Fig. 2b. This representation is not yet formalized, it is still qualitative, whereas a representation in terms of force is strongly mathematicalized (e.g. force is a vector entity, and so on).

In order to connect the different representations already built, a Body-Interaction Diagram is associated with each frame of the Event Strip.

In complex problems, loops may be necessary. For instance, suppose that in a first run a student has forgotten some characteristic time. When he/she attaches a Body-Interaction Diagram to the first draft of an Event Strip, his/her omission can become obvious. Then he/she will draw a new frame on the Event Strip. So, in spite of being used sequentially as our presentation suggests it, the cognitive aids are rather used in a very intricated way indeed.

4 -TEACHING OF COGNITIVE AIDS AND ASSESSMENT

There are two ways to teach the material we have designed : the first is a teaching made in specific training sessions separated from ordinary physics classes. In this setting, mechanics is taught as usual. Only specific sessions are added. The other way is to consider that cognitive aids are so important that their teaching is completely integrated to the regular curriculum. Then they become a part of the physics course. Both ways have been experimented. We are going to describe these different teachings more in detail and to give some information about their assessment. The whole project and its results is presented elsewhere (CAILLOT & DUMAS-CARRE, 1987)

4 - 1- Reseach context

The project here presented and its assessment is a good example of a tight collaboration between two researchers and four high-school teachers. If the teaching material was designed by the whole group, only the teachers were responsible of its teaching. However the result analysis and the project modifications were made by the whole group. The experiments were performed in 10 th and 11 th grades belonging to four high schools. The project has lasted for four years.

4 - 2 - Specific training sessions

In the first experiment, the course was taught as usual. The

cognitive aids were introduced only during problem solving activities. In general that was made at the end of a chapter or a lesson. The cognitive aids were included in "guides", sets of written instructions giving heuristics guiding the complete solution process and not exclusively the representational stage. Thus the cognitive aids were a part of a total guidance. In these specific sessions, exposition was classical and made by the teacher from some examples. So the teacher showed how to use guides on some typical problems. He/she presented the succession of elementary mental actions and introduced the specific codes. Then he/she produced Event Srips and Body-Interaction Diagrams on the blackboard. Once the resulting representation was built, he/she continued the solution by selecting a principle, choosing a system and finally doing calculations. Then the students were asked to solve new problems according to this method. They were requested to produce Event Strips and Body-Interaction Diagrams.

We have evaluated this teaching by analyzing the papers written during sessions similar to examinations. No obligation to use the method taught was required so the students might use it or not. We noticed three kinds of behaviors.

- Some students use their usual strategy without any particular reference to the cognitive aids.

- Most students draw a Body-Interaction Diagram or an Event Strip (mostly correct) but do not use at all the so summarized information or if they use it , they do it in a very limited way. For these students, the choices of a principle and a system are quite identical to the ones made by students who did not attend the specific sessions. Their global strategies are quite unchanged indeed.

- Some students use the cognitive aids to build a global and qualitative problem representation, **and** use it effectively as a basis on which they plan the subsequent solution.

We have interpreted the two last behaviors as two different levels of learning. The lowest level could be called the "technicity" level. The students have learnt the Event Strip and Body-Interactions Diagrams as technical objects which remain disconnected to the rest of knowledge. The students lack articulation between aids and strategy of problem solving. The second level deals with utility and an effective use of information summarized and organized thanks to cognitive aids. In this case the cognitive aids are used as heuristics to guide the subsequent decisions and to elaborate a strategy. As our aim was obviously that students master the cognitive aids at the second level, this first teaching experiment was a semi failure!

4 - 3 - Integrated teaching.

In the second experiment, we no longer used prescriptive guides. Firstly, during the regular mechanics classes, the cognitive aids were introduced independently and presented one by one. The teacher showed how to manage with them on some examples drawn directly from the course. During this stage there was no difference between teaching the usual domain content and each cognitive aid. No activity of physics problem solving was offered. Only a training was provided to familiarize students with an Event Strip or a Body-Interaction Diagram. At the end of a block of lessons and after learning how to manage with the four cognitive aids, problem solving activities were presented to students. The

students have been already able to build intermediate representations, so that the teacher could now focus upon the strategic aspects : he/she showed how to use the information summarized and organized in a global and qualitative representation to take decisions. He/she explicited the criteria guiding these decisions. At this stage, he/she emphasized the role of preparation and organization of a problem representation. This teaching was made on a variety of problems and then the teachers asked students to practice in the same way on other problems.

The outcomes of this teaching were very positive as we could see on different points :

- at the level of concept acquisition (interaction vs force), the students having mastered the cognitive aids do better than control students;

Insert about here Table 1

- the agreement between the choices of mechanical system made by experimental students and the drawing of free body diagrams is better than those made by control students;

Insert about here Table 2

- on rather complex problems the experimental students really use the cognitive aids as heuristics in a strategic way in order to collect and to organize information prior to take decisions.

Insert about here Figure 3

We interpret the better concept construction as follow : the teaching as it is designed obliges the students to make explicit their internal problem representation concept by concept in a very precise way. In addition the intermediate representations do not remain mental representations : they become productions such as an Event Strip or a Body-Interaction Diagram. So they are communicable and the teachers knows the student representations. Thus he/she has access to the "deep" errors and not only, as usual, to the consequences of these deep errors. For example, if a student has some difficulties with time and makes no difference between a specific time and a period of time (very common difficulty), this confusion will appear in the Event Strip because some snapshots will be missing. It is thus possible, for the teacher, to explain and to discuss what is wrong at a very basic level. He/she also has enough information to design situations inciting cognitive conflicts what enables students to overcome their errors. This is made possible thanks to the decomposition of the representation in several specific representations and by the effective production of drawings and diagrams.

The second result about the good agreement between the choice of a system and the drawing of a free body diagram shows that the students have used the qualitative representations as a basis from which they can introduce a formalized entity as force. The experimental students know to shift from a representation in terms of bodies and interactions to a representation in terms of vector entities (i.e. forces). Their free body diagrams are drawn with fewer errors : we found no extra or no missing forces on the system under consideration.

The third result is related to the global strategy followed by the

experimental students. The example here shown on Fig. 3 presents on a graph the sequence of actions performed by a student for solving a given problem versus an "ideal" order supposed to lead students towards a correct solution. The "ideal" student would be represented on this graph by a straight line whereas the "real" student is represented by a broken line. The zigzag means that when the student is stuck (point outside the squares), he is able to go back to a cognitive aid and to use it in order to build the piece of missing representation. In this last case, we could say that the metacognitive level is reached through learning.

5 - INTERPRETATION

The difference between the two methods in the teaching of the cognitive aids can be interpreted in terms of integration of concepts and methods. In the case of specific sessions of training, concepts are first learned and then the cognitive aids are added : the integration of conceptual and strategic knowledge is weak. In the second experiment, concepts and aids are learnt together. Concepts and tools which help to represent, to visualize them are met by students at the same time. Thus concepts are constructed in a more meaningful and more operative way. Students are then more able to use generic concepts to analyze specific situations. In that case the integration of conceptual and strategic knowledge is strong.

6 - CONCLUSION

The study here predented shows clearly that, firstly the student

performance for solving mechanics problemms can be improved if any teaching of solving method aims at helping students to build a useful problem representation. All aids we have designed cooperate to develop such a representation from several qualitative representations, intermediate between the verbal description given in the statement and the formalized representation specific to physics. Secondly, learning is better if the aid teaching is not separated from the teaching of physics concepts, principles and laws.

From these two conclusions, we can draw some prospective remarks. Problem solving activities in science or mathematics needs a serious analysis of domain content on which the problems are based. We know that general methods of solving are completely ineffective. So any method should be firmly grounded on physics. This remark may be extended to other domain content.

Another comment of possibly large range in education can be still made. Any teaching of a solving method whose aim is to be effective should be integrated to the corresponding regular course. Our results show that specific training sessions do not lead to a real and deep change in the student practice. On the other hand the teaching integrated to regular classes of physics has better outcomes. Such a training enables a very good unification of conceptual or declarative knowledge with procedural knowledge. Moreover our study seems to show that the metacognitive level is to some extent easily reachable with an integrated teaching. Such a learning is then more effective and more lasting.

ACKNOWLEDGEMENTS

This research has been done thanks to a contract with the INRP (Institut National de la Recherche Pédagogique) which was associated with different academic research teams in a cooperative project on "Problem Solving in Mathematics and Physics". We would like to thank particularly the teachers with whom we worked: Mrs H. Cluet, M. Goffard, M. Parisis and Mr D. Francou.

REFERENCES

Caillot M. & Dumas-Carré A., (1987). PROPHY: un enseignement d'une méthodologie de résolution de problèmes en physique, Collection rapports de recherches. N°12; 199-244. Paris : INRP.

Chi M.T.H., Feltovitch P.J. & Glaser R., (1981). Categorization and representation of physics problems by experts and novices, Cognitive Science, 5 (2), 121-152.

Larkin J., McDermott J., Simon D.P. & Simon H.A., (1980). Expert and novice performance in solving physics problems, Science, 208, 1335-1342.

Larkin J. (1981). Enriching formal knowledge : a model for learning to solve textbook physics problems. In J.R. Anderson (Ed), Cognitive skills and their acquisition. Hillsdale (N.J.): Lawrence Erlbaum Associates

Mettes C.T.C.W., Pilot A., Roosink H.J., Kramers-Pals H. (1980). Teaching and learning problem solving in science, Part I, Journal of Chemical Education, 57, 882-885.

Mettes C.T.C.W., Pilot A., Roosink H.J., Kramers-Pals H. (1981) Teaching and learning problem solving in science Part II Journal of Chemical Education, 58, 51-55.

Reif F. (1983), Understanding and teaching problem solving in physics. In Recherches en Didactique, 3-53. Paris: Editions du CNRS.

FIGURE CAPTIONS

Fig. 1 - Links between the four cognitive aids and the three intermediate representations.

Fig. 2-a - Event Strip for.

2-b - Corresponding Body-Interaction Diagrams.

Problem statement:

Two blocks A of mass m_A and B of mass m_B are linked by a string. The string is inextensible and its mass is considered as negligible compared to m_A and m_B. The block A is on an horizontal table; the contact between the block and the table is frictionless. The string passes over a pulley fixed at the end of the table. The pulley is perfect, that is to say its mass is negligible, and all contacts are frictionless. The block B hangs from the end of the string.

1) Determine the value of the acceleration of block A.

2) At a time labelled t_1, the block B reaches the ground. Determine the value of the acceleration of the block A at a time t>t1.

Fig. 3 - Graph of the effective action order vs an "ideal" action order.

The numbers on the horizontal axis correspond to a list of actions proposed by the taught strategy. A corresponds to the global qualitative representation (use of cognitive aids, elaboration of the intermediate representations), B corresponds to explicit choices, C corresponds to the limited physics representation, D corresponds to the instanciation preparation, E to the actual instanciation of the principle and R to the result.

The numbers on the vertical axis correspond to the successive actions performed by the student.

A student following strictly the taught strategy would have all the points of the graph on the bissector.

TABLE CAPTIONS

Table 1 - Percentage of correct answers to a test assessing the conceptual understanding of an interaction between two bodies. The property of symmetry and the differentiation between the ground as source of a contact action and the Earth as source of a long range action were tested for experimental students and control group.

Table 2 - Percentage of relevant choices of a system and of correct free-body diagram for 3 different kinds of problems (statics, solid in translation and solid in rotation) for experimental students and a control group.

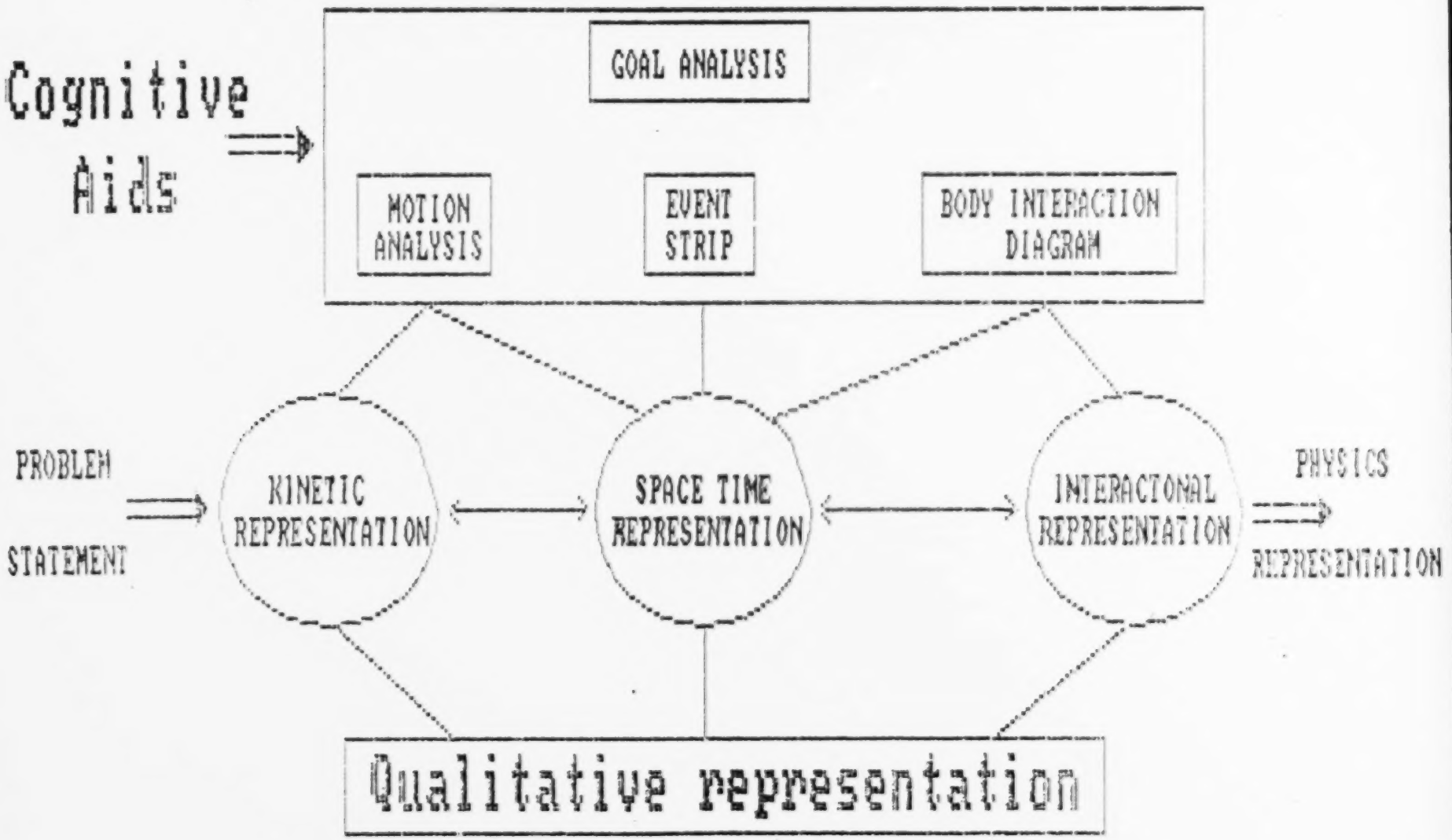

Cognitive Aids
GOAL ANALYSIS
MOTION ANALYSIS
EVENT STRIP
BODY INTERACTION DIAGRAM
PROBLEM STATEMENT
KINETIC REPRESENTATION
SPACE TIME REPRESENTATION
INTERACTONAL REPRESENTATION
PHYSICS REPRESENTATION
Qualitative representation

Figure 1

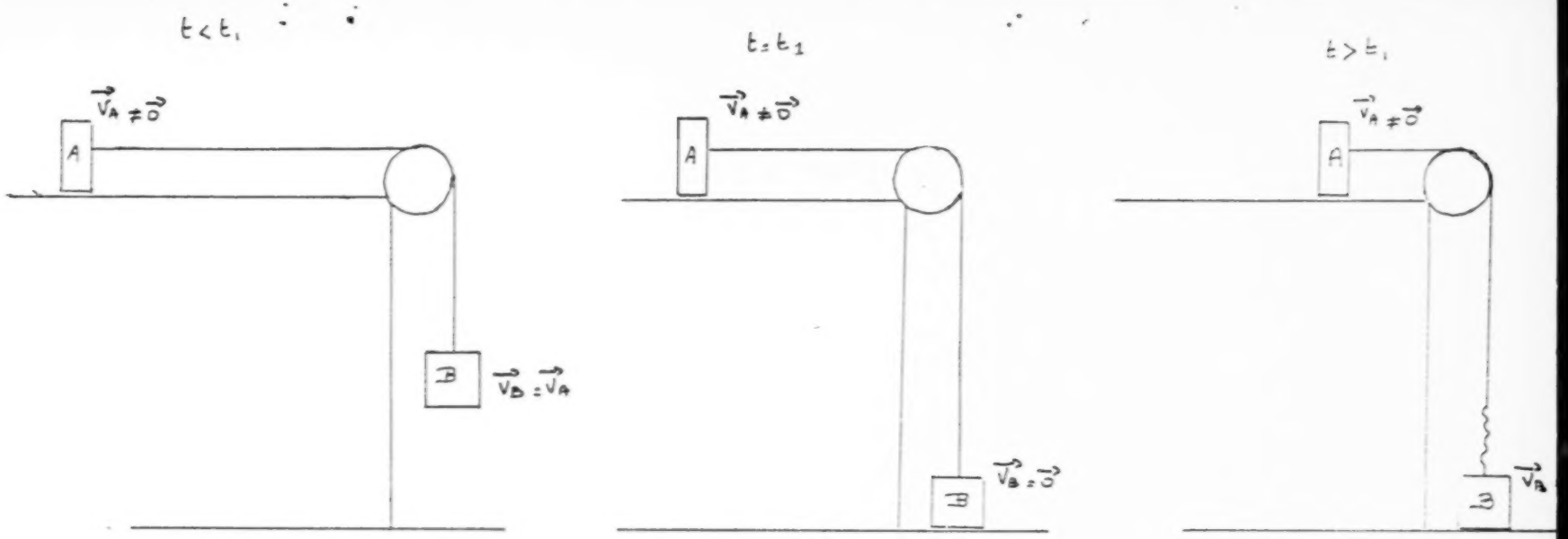


FIGURE 2 a

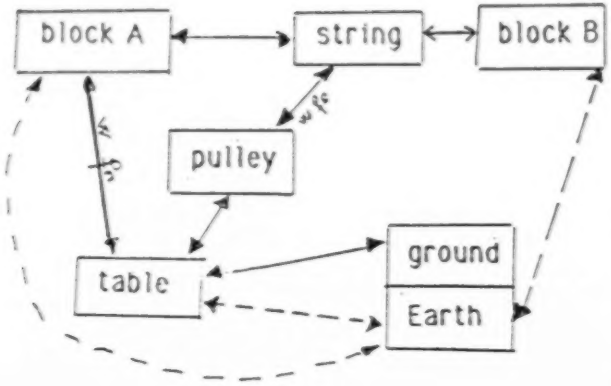
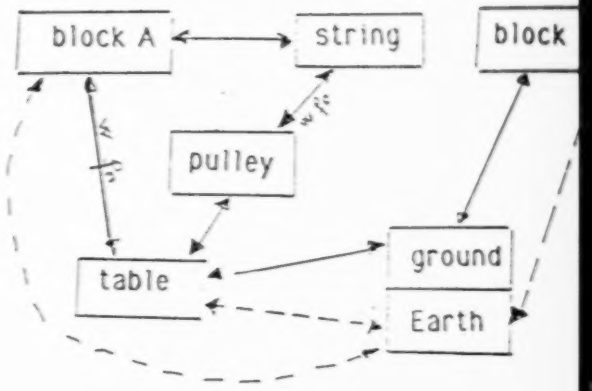


FIGURE 2 b

No B.I.D. at t1
two interactions
are just changing:
string/B vanishes,
B/ground appears



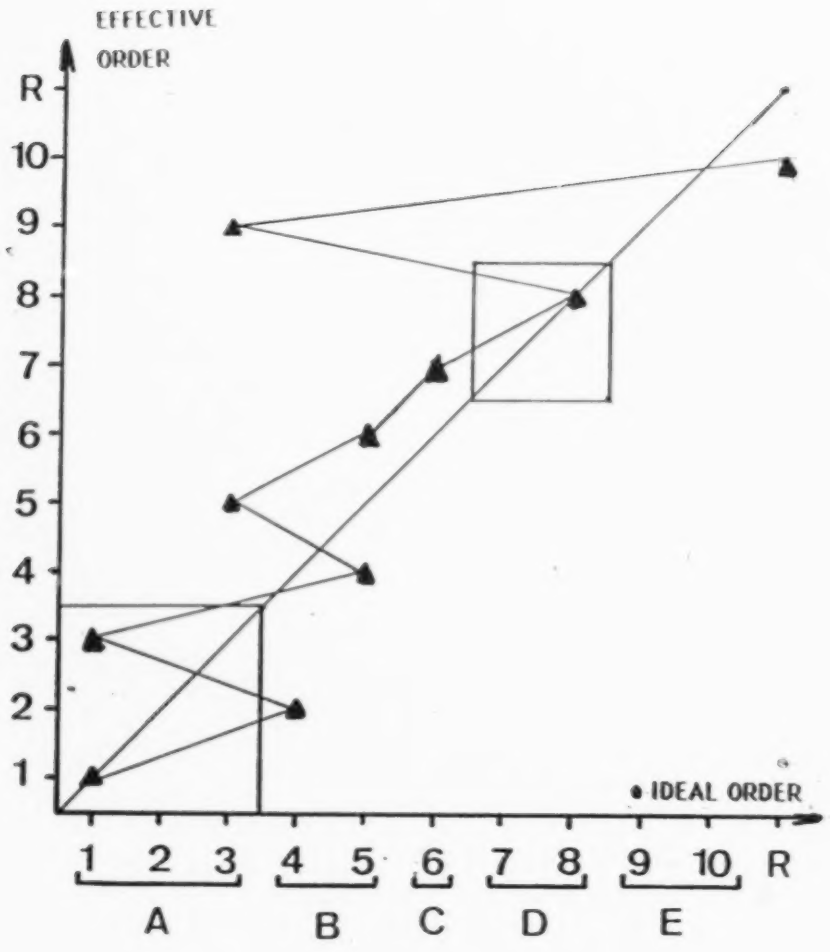

EFFECTIVE
ORDER
R
10
9
8
7
6
5
4
3
2
1
• IDEAL ORDER
1 2 3 4 5 6 7 8 9 10 R
A B C D E

FIGURE 3

CONCEPT PROPERTY		EXPERIMENTAL GROUP (N = 39)	CONTROL GROUP (N = 112)
SYMMETRY OF THE INTERACTION	CONTACT INTERACTION	92%	75%
	LONG RANGE INTERACTION	54%	35%
DIFFERENTIATION BETWEEN CONTACT AND LONG RANGE INTERACTION	CONTACT (ground)	76%	43%
	LONG RANGE (Earth)	87%	75%

TABLE 1

PROBLEM	RELEVANT CHOICES OF THE SYSTEM		CORRECT FREE-BODY DIAGRAMS	
	EXPERIMENTAL	CONTROL	EXPERIMENTAL	CONTROL
STATICS	96%	42%	79%	37,5%
TRANSLATIONAL MOTION	94%	46%	79%	37,5%
ROTATIONAL MOTION	100%	81%	70%	42%

TABLE 2